Design of Embedded Computer Numerical Control System Based on STM32F407

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Abstract

CNC technology has not only brought innovation to the traditional manufacturing industry, but also promoted the rapid development of high-technology industry. The core of computer numerical control technology is the CNC system. The high-end CNC system is very expensive, and the low-end market capacity is very big; therefore, an embedded highly cost-effective low-end embedded CNC system is designed to develop. This paper introduces the characteristics of STM32F407 controller. It proposes a new embedded CNC system based on this processor. It analyses hardware architecture, software design method and achieved function of this CNC system. The system has conducted experiments testing and engineering applications, and the results showed that the achieved function is complete correct, the speed and accuracy has met the requirements, high efficiency has achieved. And it has a much lower cost, therefore it got a certain application in practice and actual production.

Keywords

STM32F407 Controller; Embedded CNC System; Hardware Platform; Software Design; Achieved Function

Introduction

STM32F407 is a high-performance digital signal controller, which is based on the kernel of the latest embedded processor ARM Cortex M4. It is often used to a hybrid digital control market of control and signal processing. The Cortex-M4 kernel has the function of DSP processing instructions with enhanced floating point operations, huge storage, 1Mbytes of on-chip flash memory, 196Kbytes of embedded SRAM and flexible external memory interface. The controller (MCU) improved the operation speed. Its working frequency is 168MHz. And it has obtained the widespread application on the market. Aimed at NC machine tools, machining center and other fields, this paper applied the controller of cost-effective, designed a STM32F407IG as the core processor of the CNC digital controller. After analyzing the characteristics of the STM32F407IG, CNC numerical control system is put forward to it as the core of the design. It describes in detail the system hardware design and software realization function and conducts experiments. The practical operation results show that STM32F407 CNC system processor can achieve the functions of CNC, including CNC machine tools, machining center and so on. It played a great role in the actual production practice due to low price and good performance.

CNC controller refers to Computer numerical control machine process control system. It is able to handle the control code or other symbolic instruction specified program logically. Through the computer's decoding, the machine can implement the provisions of good actions. By tool cutting blank material will be processed into semi-finished products or production parts. All of these improved the mold processing productivity. CNC technology has not only brought innovation to the traditional manufacturing industry, but also promoted the rapid development of high-technology industry. High performance CNC system has been widely applied in automotive, mold, marine, aerospace, and other industries. But now the price of high-end CNC system is particularly high, it is unbearable for ordinary users to use in the price. Instead low-end CNC system has a high market share in the country. Currently there are many forms of CNC systems, which can be divided into open CNC system based on PC and microprocessor-based embedded numerical control system. Advantages of open PC-based CNC system are development of convenient, good openness, abundant system resources and standard interface, but it's biggest drawback is poor real-time, low stability with large volume and high cost, which limits the application in some cases. CNC system based on embedded microprocessor is currently developing very rapidly, and it becomes a hot topic in the field of NC in recent years. Embedded CNC system has many advantages. It is the perfect merging of embedded and CNC technology. It has been widely applied in many areas due to its small size, low power consumption, cut hardware and software and high stability and

reliability. This paper proposed a lower cost, more compact, high-performance embedded numerical control system with independent intellectual property rights according to the current development in the form of embedded CNC system. It uses a high-performance ARM Cortex M4 core embedded processor STM32F407, whose internal abundant hardware resources reduces the manufacturing cost of the entire CNC system. STM32F407 has high-performance digital signal processing functions, it can fully qualify the function of the low-end CNC system implementation.

CNC System Hardware Design

CNC system hardware is the physical basis of software system's running, in addition to the requirements of high computing power; it also needs to have strong anti-interference ability, good stability, high reliability, and the need to consider the cost of production. The system uses hardware circuit STM32F407 processor mainly, and block diagram is shown in Figure 1. In addition to the main system processor, the other circuit structure is modular in design to reduce hardware complexity, and easy to debug and maintain. System modules include power modules, motion control modules, input and output modules, human-computer interaction modules and panel control modules etc.

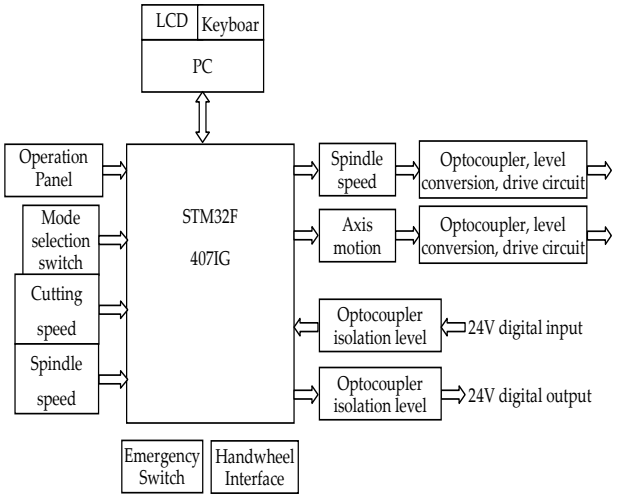

FIG. 1 CNC SYSTEM HARDWARE BLOCK DIAGRAM

The system uses STM32F407 as main control system, all types of CNC machining capabilities are achieved by software program. In the system, indle control was achieved by using PWM. User set the spindle speed according to processing codes, then the processor accepted the parameter and calculated the corresponding PWM duty cycle, finally, output it to IO pin. The output PWM signal is isolated through the TLP281 optocoupler, and the level is converted to 12V, then the corresponding PWM voltage controlling spindle speed was output through the DA circuit and operational amplifier. Other control functions were provided to realize spindle's stop rotation, clockwise and counter-clockwise. This system can realize 6 axes motion controls, respectively X, Y, Z motion axes and A, B, C rotation axes. The output pulse and direction signals of each axis were controlled by software. These signals were isolated through high speed optocoupler HCPL-2630 and output to each axis control driver to realize motion and rotation. The system accepted a variety of digital inputs and outputs synchronously, including going homing, limiting signals of each axis, all kinds of changing machine tool's signals, each electromagnetic valve switch signals, the positive and negative rotating of machine tools wareroom, the forward and reverse of spindle, the output controls of liquid, mist, gas and oil, various kinds of indicator lights and light control, rigid tapping control and so on.

The host controller communicates with upper computer by serial port. The user realizes man-machine interaction or processing code through the PC keyboard and LCD screen. Meanwhile the system provides operator panel, enabling each digital output control functions and providing the appropriate LED indicator.

The system also has three knob control switches, which are mode control knob, cutting speed selector knob, spindle speed selector knob. The mode control knob can set the mode of the system from more than eight modes. The modes are AUTO (the system comes into the automatic processing model), EDIT (used to input NC program or edit program directly through the operation panel), MDI (manual data input), HOME (going to reference point), MPG (moving work table or machine tool using hand wheel), JOG1 (manual mode, continuously moving work table or machine tool, speed 1 file), JOG10 (as JOG1, speed 10 file), JOG100 (as JOG1, speed 100file). The cutting speed selector knob is used to manually adjust the cutting speed temporarily when cutting speed is not appropriate under current setting. It is divided into sixteen files, namely 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 100%, 105%, 110%, 115%, and 120%. Spindle speed selector knob is used for manual adjustment of spindle speed, adjusted to eight files in the current spindle speed, which are 50%, 60%, 70%, 80%, 90%,

100%, 110%, and 120%.

Emergency stop switch is installed in the system. When abnormal or unusual danger occurs, the switch can be pressed to emergently stop equipment's any functional unit, so as to ensure safety. The system also provides a hand wheel interface, commonly used with handheld pulse generator. In the hand wheel mode the system can realize to control the axis movement under the hand wheel operation, its speed and direction of axis are completely controlled by the user's hand wheel.

TABLE 1 SYSTEM IMPLEMENTATION INSTRUCTION AND FUNCTION DESCRIPTION

Function Module	Instruction Code	Description
G Code	G0,G1,G2,G3	Linear and arc interpolation
	G4	Dwell
	G10	Coordinate system data
	G17,G18,G19	XYZ plane selection
	G20,G21	Select a unit of length
	G28,G28.1	Homing control
	G40,G41,G42,G43, G49	Tool radius, length compensation
	G53,G54-G59	Absolute coordinates, relative coordinates select
	G61,G61.1,G64	Path control mode selection
	G80	Cancel sport mode
	G81-G89	Closed loop control
	G90,G91	Absolute-incremental distance selection
	G92,G92.1,G92.2, G92.3	Coordinate system offset
	G93,G94	Cutting feed speed mode selection
	G98,G99	Closed loop return level setting
M Code	M0,M1,M2,M30, M60	Program stops, end of the control
	M3,M4,M5	Spindle clockwise, reverse, stop
	M6	Tool change control
	M7,M8,M9	Cooling output control
	M48,M49	Disable / enable speed control coverage
others	X、Y、Z、A、B、C、T、F、P、S、I、J、K、Q、R、N、H、D、L	Various parameters configuration

CNC System Software Design

In the above hardware platform, the paper developed CNC software based on STM32F407 processor. In order to further improve the performance of the processor, this system gave up the embedded operating system, and developed the program directly based on the hardware platform. The system can conduct a man-machine interface communication with upper computer through the serial port. The operator can realize control not only by PC's command or processing code, but also through the operation panel.

The functions of the system according to the code can be divided into three categories. They are G codes, which realize the function of all kinds of motion control preparation instructions, M auxiliary function codes, and other parameters configuration instructions, specifically as shown in Table 1.

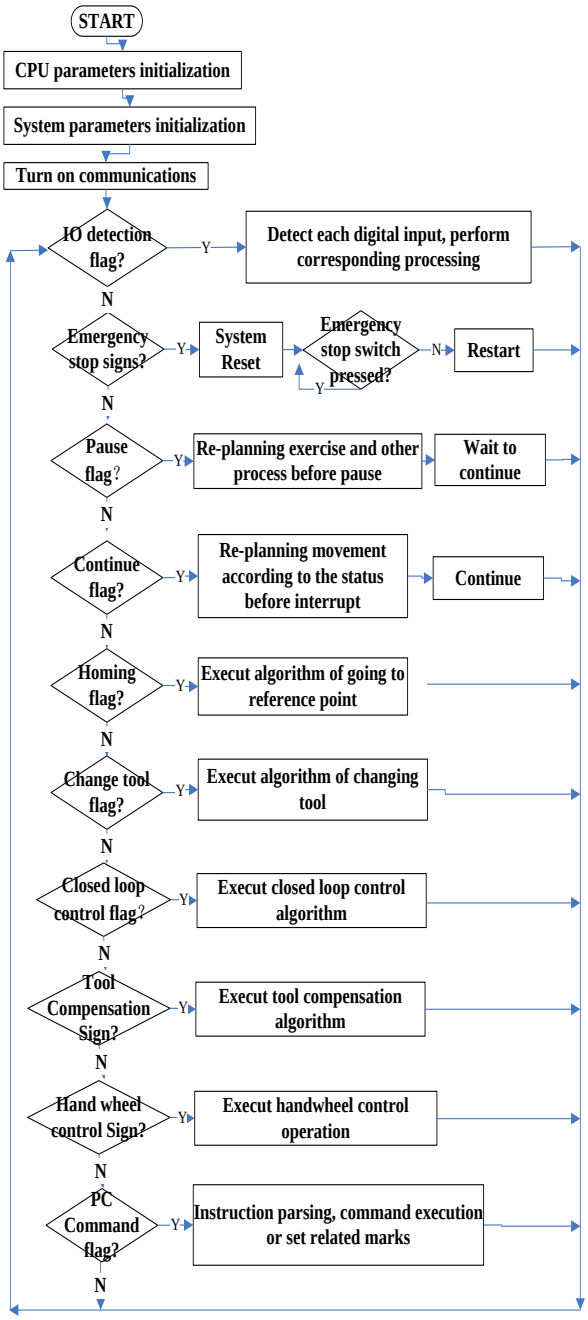

FIG. 2 PROGRAM EXECUTION FLOW

System processor mainly receives three instructions types: the first is the commands sent by the upper computer communication interface, including processing program codes, upper PC manual instructions and so on. The second is the user panel

operations, including panel buttons, various rotary switches and user's hand wheel operation and so on. The third is the treatments of changes of the external digital input signals. Specific implementation process is shown in Figure 2. Because the numerical control equipment's movement, including platform or tool movement, should be implemented according to the instruction code, while it needs processing velocity or acceleration of the planning for start or end processing, pre-processing is needed, after receiving code, then to set the processing of all kinds of configuration, in order to make the movement process more smooth and processing speed more faster. Several algorithms are used in the system: one is steady-state jerk, namely the acceleration changing uniformly in the beginning and at the end of movement. The second is forecast, that is related convergence around the different trajectories. The third is turning angle control. It can also be seen from the diagram that, after it received the instructions, it needs to parse instruction, perform commands and configuration parameters, or mark which are related, further to carry out the motion planning and so on, rather than directly to carry out the movement control. Overall control function modules can be divided according to Fig3.

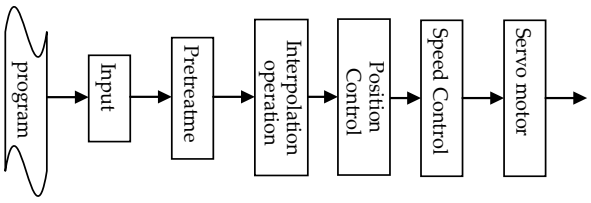

FIGURE 3 CONTROL FUNCTION MODULE

Conclusions

This paper describes the embedded numerical control system based on the ARM CORTEX M4 of STM32F407 in detail. It concludes hardware design, principle block diagram, system software, and the functions of this system can be achieved. The controller is the control center of CNC machine tools and machining center. The system has independent intellectual property rights and source code, so it can realize the user private processing code by programming. Six axes linkage system is currently implemented. The axis number and corresponding functions can be easily extended. The controller system has been used in some machining centers, the correct results and better performances are achieved.

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